urban science

Perspective

Connected Institutions: Using Platform Powers to Advance Transport

David Levinson

School of Civil Engineering, The University of Sydney, Sydney 2006, Australia; david.levinson@sydney.edu.au

Abstract: This perspective paper analyzes selected policy strategies for transforming transport. It identifies four primary objectives: enhance economic efficiency, increase equity, reduce negative externalities, and improve the user experience (4Es). It then develops the framework of persuasion, police, purse, and platform powers (4Ps), which are available to governments to implement change and pursue their objectives. In a series of cases, it illustrates those powers, particularly the underappreciated platform powers, the formation and promulgation of standards, which are themselves the key technology for connecting institutions, showing how the establishment of technical standards transforms existing transport and lays the groundwork for new opportunities.

Keywords: standards; investment; taxation; regulation; exhortation

check for updates

Citation: Levinson, D. Connected Institutions: Using Platform Powers to Advance Transport. *Urban Sci.* **2024**, *8*, 245. https://doi.org/10.3390/urbansci8040245

Academic Editor: Chia-Yuan Yu

Received: 26 October 2024
Revised: 26 November 2024
Accepted: 2 December 2024
Published: 4 December 2024

1. Introduction

The transport sector witnessed transformative technological and social changes in the 2010s, unmatched since the 1920s. These are often referred to as the three revolutions—automation, sharing, and electrification [1]. Significant shifts were also observed in logistics, commuting patterns, the rise of remote work, the dematerialization of goods, ubiquitous sensing technologies, and the advent of electric micromobility [2]. These changes are still in their infancy but are increasing exponentially, requiring a wide range of institutional policy responses.

Institutions, defined by Huntington [3] as "stable, valued, recurring patterns of behavior", are pivotal in this context. This paper explores institutions both as *organizations*—including governments at various levels, private firms, universities, NGOs, and standard-setting bodies—and as *practices*, encompassing standards, laws, norms, regulations, documents, and the tacit knowledge that govern the provision of transport services and innovations.

This paper identifies four primary objectives for improving transport systems: enhancing economic efficiency, increasing equity, reducing negative externalities, and improving the user experience—termed the "4Es". To achieve these goals, governments and institutions can deploy four types of powers: persuasion, police, purse, and platform—the "4Ps". While persuasion, police, and purse powers have long been central to governance, this paper highlights the critical yet often underappreciated role of platform powers in transforming transport systems. Platform powers enable governments to establish and promulgate standards that connect institutions and systems, fostering interoperability, innovation, and resilience.

Through practical examples, it populates a matrix of aims versus tools (Figure 1), striving to deduce general principles about the effectiveness of different strategies and the conditions for their success. This paper particularly emphasizes technological standards because they act as critical connectors among institutions, enable future innovations, and have historically been under-addressed by mainstream transport entities.

The analysis focuses on the interaction between these organizational forms and practices, examining how they interface and how actors engage across institutional boundaries. It aims to identify effective rules (standards, conventions, norms) that could support the deployment of transformative transport technologies and practices. By reviewing case studies of technical standards—such as those for transit schedules, curb usage, and traffic signal data—and policy measures for agency coordination, the paper identifies mechanisms that facilitate inter-institutional collaboration.

This *perspective* paper aims to advance the discussion on transport governance by illustrating the potential of the 4Ps framework to address contemporary challenges. By synthesizing insights from the literature and case studies, the paper proposes a new approach to leverage institutional powers to create more connected, equitable, and user-centered transport systems.

Public Sector Tools		Aims			
		Efficiency	Equity (incl. Human Development, Affordability)	Environment	User Experience (incl. Safety, Privacy, Security)
Persuasion Powers		*Variable Message Signs encouraging carpooling*	Change operator behavior towards special need populations	*Clear the Air Days*	Buckle-up Campaigns
Police Powers	Regulation	Anti-trust	Ride Hailing (regulation to protect users, incumbents)	*International Market in Used Vehicles and Parts*	*Dockless Bikesharing in China* Airport Security
Purse Powers	Subsidy (to consumers, producers)	Railroad Land Grants	Public Transport Fares	Bike Sharing, EVs, Intercity Rail Electrification	
	Taxation and Tolling	Congestion Charge	Lifeline transit passes	Carbon Tax	
	Finance and Investment	*Asset Recycling*	Public Port Subsidies	Public EV Charging Stations	New Airport Construction
Platform Powers	Technological Standards	*National ITS Architecture; Curb Standards, Ride-Hailing (MDS), Traffic Signal Standards; Cross-Sections, Traffic Count and Speed Data, Real-Time Tolls and Road Prices*		EV Charging Stations standards	*Transit (GTFS), Bikesharing (GBFS)*
	Scientific Platform Research and Development	Autonomous Vehicles		EVs and Battery Technology	Autonomous Vehicles

Figure 1. Aims vs. Tools, sorted by illustrative Applications (successes and failures). Each application is contextualized by place and time, along with the associated institutions. Cases are derived from this matrix (*shown in italics*). Discussion on applications for emerging transformative transport technologies is included in the text.

2. Public Aims

Public policy frequently targets four primary objectives: economic efficiency, social equity, reductions in externalities, and the enhancement of user experience. Collectively referred to as the "four Es", these goals provide a robust framework for evaluating public initiatives [4].

Economic *efficiency* focuses on optimizing *access*—the ability of individuals to reach people, goods, and services that are important to them [5]. Urban centers serve as hubs for economic and social exchange, where transport networks play a pivotal role in enhancing connectivity and reducing the friction of distance. Efficient transport systems support this connectivity by enabling the faster, more reliable movement of people and goods.

Social *equity* is multifaceted and often debated, with no universal definition. It can be understood both descriptively, in terms of the distribution of opportunities and benefits, and normatively, in terms of fairness and justice in outcomes. Policies aimed at improving equity can sometimes trade off with efficiency. For instance, spreading low-frequency bus services over extensive areas may achieve spatial equity but compromise service quality in denser regions [6]. Equity considerations often include assessing whether specific groups—such as lower-income households—experience comparable access to jobs and services relative to the broader population [7,8].

Negative *externalities* encompass the unintended consequences of transport activities, such as congestion, noise, increased crash risks, environmental pollution, and carbon emissions. While these are not the goals of transport systems, they are inherent byproducts of their operation. Addressing these externalities is critical for creating sustainable and socially responsible transport systems.

User *experience* reflects the subjective perceptions and interactions individuals have with the transport system. This includes attributes such as ride comfort, safety, and reliability, which are often undervalued in traditional analyses focused on time and cost metrics [9–11]. Incorporating user experience into evaluations ensures a more holistic assessment of transport initiatives.

The four Es—efficiency, equity, externalities, and experience—offer a structured approach to assessing transport policies within an access framework. From a societal perspective, access includes not only individual costs and times but also the broader social costs of providing that access, including infrastructure expenditures and externalities [12]. Equity considerations extend to how access is distributed across spatial, socioeconomic, or demographic groups. Metrics like Gini indices can capture disparities, while accessibility measures help evaluate whether lower-income or disadvantaged groups have equitable access to essential services [13,14].

3. Public Powers

Traditional strategies for achieving public policy objectives typically employ three types of powers:

- *Persuasion* powers: These rely on exhortation and example setting, which, aside from times of crisis, tend to have limited impact.
- *Police* powers: Direct regulation and enforcement shape the urban form and affect vehicle technology [15,16]. However, the influence of police powers has been challenged in recent years by emergent technologies such as Google's automated vehicle tests in California [17], Uber's ridehailing services [18], and Tesla's Autopilot system [19], often introduced in defiance of existing regulations.
- *Purse* powers: Subsidy, finance, investment, contracting, and taxation, often backed by police powers, have long been considered critical levers in policy implementation.

Standards permeate every aspect of modern life, facilitating consistent communication and operation within society [20,21]. For example, the English language serves as a global communication standard, the QWERTY keyboard layout has endured for over a century, and SI units [22] ensure uniformity in scientific measurement. Time zones [23], standardized shipping containers, and adherence to traffic rules—whether driving on the right or left side—demonstrate the ubiquity of standards. These examples highlight the role of standards in maintaining order and interoperability across diverse systems.

- *Platform* powers represent an additional type of governmental influence: establishing technological standards that govern interfaces and information exchanges across systems. These powers are particularly significant in transport, where the development of standardized data formats, communication protocols, and operational systems underpins interoperability and innovation. Governments—especially large national and supra-national entities—possess platform powers as both producers and consumers. These powers are as influential as persuasion, police, and purse powers in enabling transformative societal change.

While distinctions among the 4Ps can blur, their applications and implications vary significantly. For instance, zoning regulations [24] set *performance standards*, such as setbacks from streets or street widths, to ensure operational compatibility. In contrast, *technological standards* address data exchange or system interfaces, such as defining vehicle density to maintain service levels.

The matrix in Figure 1 illustrates the interaction between public aims and tools, providing context through illustrative applications—both successful and unsuccessful. Each scenario is tied to a specific time and place, underpinned by institutions (both organizations and practices). The forthcoming discussion organizes cases by type of power: persuasion (Section 4), police (Section 5), purse (Section 6), and platform (Section 7).

Figure 1 cross-tabulates powers against goals, suggesting that each standard addresses specific objectives (efficiency, equity, environment, or experience). This is guided by two economic principles:

> "Achieving a multiple number of independent policy targets requires an equal number of policy instruments."—Jan Tinbergen [25]

> "Each policy instrument should be assigned to a policy target on which it has the greatest relative effect."—Robert Mundell [25]

Although many strategies and standards serve multiple aims, the 4Es and 4Ps provide a general framework applicable to any policy instrument. This *perspective* paper applies the 4E/4P framework across diverse transport policies, demonstrating its versatility with a particular focus on emerging transformative transport technologies. The examples span various contexts, including mature and emerging systems, developed and developing economies, and a range of market types, from small enterprises to large technology producers and across both rural and urban settings.

4. Persuasion Powers

Persuasion powers are generally regarded as limited in effectiveness within the transport community, often serving to satisfy political agendas rather than producing tangible results. An illustrative case is the 'Bike Month' initiative in Sacramento, designed to boost bicycle usage and enhance cyclist safety through the 'safety in numbers' effect. However, Malik et al. [26] found that while the initiative temporarily increased bicycle use, it failed to induce lasting changes. These short-term efforts stand in contrast to more enduring programs like 'Safe Routes to School', which combine persuasion with police and purse powers to alter the physical environment and consistently encourage behavioral change, leading to more sustained impacts [27,28].

Other initiatives leveraging persuasion powers include 'Clear the Air' days, targeted at mitigating air pollution by reducing travel during adverse meteorological conditions. Studies in Salt Lake City found these efforts largely ineffective [29], echoing the outcomes of similar programs in other regions.

Despite these challenges, persuasion tools can be impactful in specific contexts. For instance, Variable Message Signs (VMSs) that alert drivers about upcoming crashes can effectively modify travel behavior by suggesting alternative routes [30]. The success of VMS lies in providing immediate, actionable information that benefits both the individual and society, unlike broader campaigns like 'Clear the Air' days, which often impose personal costs for societal gain.

Given these observations, policymakers aiming to enhance social welfare are increasingly cautious about approaches that rely solely on rhetoric without enforcement or financial incentives. Consequently, strategies often pivot toward interventions supported by police and purse powers, which offer greater enforceability and alignment with long-term policy objectives.

5. Police Powers

Police powers, defined as the authority granted to governments to regulate the behavior of travelers and organizations, are fundamental in transport. These powers, underpinned by the government's monopoly on the legitimate use of force, encompass a broad spectrum of regulations, including driving laws and vehicle ownership rules. This section discusses two critical areas impacted by police powers: the international market in used vehicles and parts (Section 5.1) and dockless bikesharing in China (Section 5.2).

5.1. The International Market in Used Vehicles and Parts

The global surge in electric vehicle adoption, particularly in Europe, has raised significant concerns about the fate of second-hand internal combustion engine (ICE) vehicles. Between 2015 and 2018, the three largest exporters of used light-duty vehicles (LDVs)—the European Union (EU), Japan, and the United States—shipped 14 million units worldwide [31]. The EU led these exports, contributing 54% of the total, with primary destinations in West and North Africa. Japan and the USA followed, exporting primarily to Asia, East and Southern Africa, and the Middle East and Central America.

This trend presents substantial challenges for environmental sustainability, particularly in mitigating pollution and CO_2 emissions. Used vehicles, often built under older, less stringent environmental regulations, tend to be less efficient and environmentally friendly as they age. Their continued operation in regions with lax environmental standards exacerbates pollution and negatively impacts public health. A study in the Netherlands indicated that over 80% of vehicles exported to West African countries would fail to meet those nations' tightening environmental standards [32].

The trade in older vehicles also raises safety concerns due to the diminished efficacy of aging safety features. The UNEP report advocates for stricter international regulations on used vehicle trade to enforce environmental and safety standards [31]. However, such measures could reduce the supply of affordable vehicles to importing nations, potentially impacting economic activity and accessibility. Balancing environmental benefits with economic drawbacks requires comprehensive policy analysis.

Alternative strategies leveraging purse powers include 'cash for clunkers' or 'scrappage schemes', which phase out older, polluting vehicles by purchasing and recycling them rather than reintroducing them into the used vehicle market. While these programs can reduce emissions, their effectiveness depends on accounting for the environmental costs of manufacturing new vehicles [33].

Another pressing challenge involves the disposal and recycling of used electric vehicle batteries [34]. These batteries, once no longer efficient for vehicular use, can be repurposed for solar storage or recycled to recover valuable materials, mitigating the environmental impact of mining. Standardizing battery sizes and vehicle-to-grid (V2G) charging interfaces—supported by platform powers—could enhance recycling efficiency and encourage sustainable practices.

5.2. Dockless Bikesharing in China

Bikesharing serves as both a direct mode of transport and a solution to the first/last-mile problem, enhancing the efficiency of longer-distance public transport systems. Initially, in the early 2010s, station-based bikesharing catered primarily to point-to-point travel, requiring users to pick up and return bikes at designated stations.

As shown in Figure 2, the advent of smartphones, GPS technology, and affordable batteries catalyzed the rise of dockless bikesharing in China in late 2016 [35], which then spread globally. Dockless systems offer greater locational flexibility, serving a broader range of user needs, particularly as a first/last-mile solution. Studies confirm that bikesharing has bolstered public transport usage, particularly subway lines [36–38].

By 2017, Beijing alone hosted 15 bikesharing companies. Mobike's daily usage grew exponentially from 18,000 users in June 2016 to 979,000 by January 2017, while competitor its Ofo expanded from 13,000 daily users to 487,000 over the same period [35]. However, this rapid expansion led to oversupply, with Beijing hosting 2.35 million shared bikes at its peak in September 2017, many of which went unused. In 2018, Meituan, a major online retailer, acquired Mobike for USD 2.7 billion amidst financial struggles [39]. Today, three major companies dominate China's market, Hello, Qingju (under Didi), and Mobike (under Meituan), each leveraging its own online payment system and varying in popularity across cities.

Figure 2. Shared bikes near Tongji University in Shanghai in 2017. Photo by author.

For instance, Hello reported having 10 million shared bikes and e-bikes across 400 cities, with approximately 100 million active users in 2020, accounting for 5.1 billion bike trips at an average cost of USD 0.17 each. One in five trips used an electric bike, contributing to total revenue of USD 926 million in 2020 [40].

In response to the proliferation of bikesharing companies and the perceived oversupply, the Beijing Municipal Government imposed regulations to reduce the total number of bikes to around 900,000 units [41]. To enforce these regulations and maintain order, new roles such as bike dispatchers emerged, tasked with organizing bikes around major destinations. Dispatchers also manage bike distribution and maintenance, a growing operational need since 2017 [42]. However, the reuse and recycling of shared bikes and their e-bike batteries remains a significant challenge. E-bike batteries, in particular, face similar disposal and recycling issues as those of electric vehicles.

The success of bikesharing strongly correlates with urban infrastructure. Chinese cities, with their extensive network of high-quality bike lanes, provide a conducive environment for bikesharing adoption. Conversely, cities like Sydney, which lack comparable infrastructure, have struggled with dockless bikesharing systems [43].

The evolution of new technologies often prompts governmental regulation. Depending on the regulatory approach—whether permissive except for prohibitions or prohibitive except for permissions—technologies like dockless bikesharing can either thrive or be stifled. While dockless bikes have improved urban mobility, they also present negative externalities such as footpath congestion, which require thoughtful regulatory responses.

6. Purse Powers

Purse powers represent the financial strategies employed by governments to drive change, often through the allocation of funding for infrastructure projects. This approach is widely used, with subsidies for new infrastructure frequently aimed at stimulating economic and social improvements.

An example of purse powers in action is the implementation of road tolls. While primarily a revenue-generating mechanism, tolls also integrate police powers for enforcement. Congestion pricing is a notable application of this strategy. However, its adoption has been limited due to political challenges. Among the few successful instances, Singapore's congestion pricing model stands out, attributed to its unique circumstances rather than as a universally applicable solution [44].

A specific illustration of purse powers is the Asset Recycling initiative in Australia (Section 6.1).

6.1. Asset Recycling in Australia

Introduced in the 2014–2015 federal budget, the Australian government's Asset Recycling Initiative Fund (ARIF) incentivized state governments and territories to privatize or lease existing assets. The initiative aimed to reinvest proceeds from these transactions into new infrastructure projects, with the federal government providing a 15% bonus on the sale price to encourage participation. A budget of AUD 5 billion was allocated for this purpose.

The state of New South Wales (NSW) was a prominent participant, leasing TransGrid, its high-voltage electricity transmission network, for 99 years at a price of AUD 10.3 billion. The proceeds from this transaction were used to fund the Sydney Metro project.

While asset recycling generates significant immediate capital, it also poses long-term risks as governments forgo future revenue from privatized assets, relying instead on potential taxable income. The profitability of reinvested funds is uncertain, introducing financial risks for the government. Moreover, concerns about transparency in privatization deals—often classified as "Cabinet-in-Confidence" or "Commercial-in-Confidence"—have raised questions about democratic accountability.

Additionally, simultaneous large-scale infrastructure developments can strain the construction sector, leading to cost inflation and delays [45].

7. Platform Powers

Platform powers encompass the ability to direct long-term change by setting the rules of the game, rather than merely participating in it. This section explores various aspects of platform powers, such as failed standards (Section 7.1), successful standards (Section 7.2), emerging standards (Section 7.3), and missing standards (Section 7.4). Additionally, it examines the relationship between standards and innovation (Section 7.5).

7.1. Failure to Launch—National ITS Architecture

Platform powers encompass the ability to direct long-term change by setting the rules of the game, as illustrated by the development of the National ITS Architecture. Post-Cold War, the US government initiated a national industrial policy to repurpose defense contractors' expertise, given the reduced threat from the dissolved Soviet Union. Intelligent Transportation Systems (ITSs) were among the projects supported, with the primary goal of redirecting industrial capabilities and a secondary aim of improving transport. The National ITS Architecture was established to create a standardized, interoperable framework for intelligent transport systems nationwide. A top-down, systems-engineering approach, inherited from defense practices, was applied to define how various components of the transport system would interact.

One prominent demonstration of this initiative was the National Automated Highway System Consortium's (NAHSC) DEMO 1997 in San Diego, CA. This demonstration, illustrated in Figure 3, showcased an Automated Highway System (AHS) on the reversible High-Occupancy Vehicle (HOV) lanes of I-15. Specially equipped vehicles maintained close distances (6.4 m) at high speeds without driver intervention, using vehicle-to-vehicle (V2V) communications and in-road magnets for lane guidance. Despite its technical success, the project was discontinued when funding was cut, leading to the disbandment of the NAHSC.

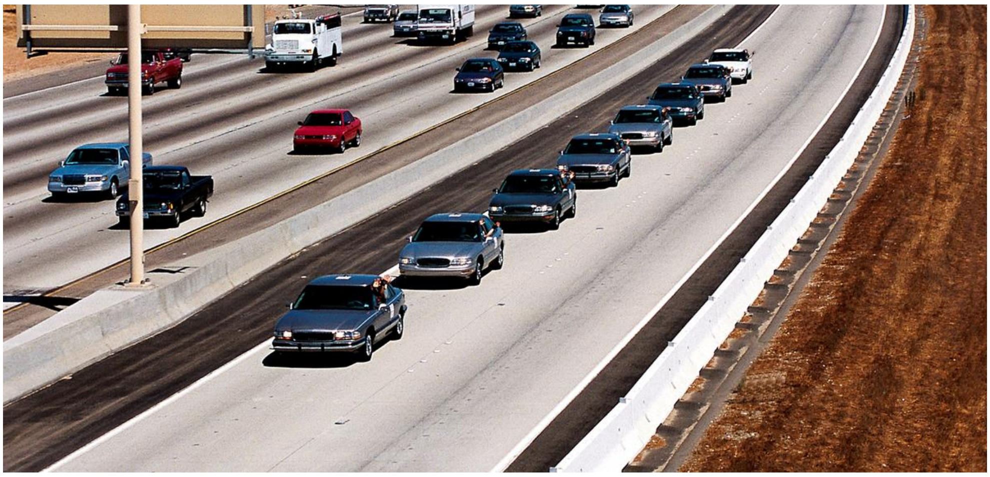

Figure 3. I-15 Demo of Automated Highway System, 1997. Source: National Automated Highway Systems Consortium, California PATH.

The deployment of connected vehicles (CVs or V2X), which this technology would now be categorized under, proved more challenging than autonomous vehicles (AVs). While AVs and CVs share similar underlying technologies, CVs depend heavily on widespread adoption and supporting infrastructure. This creates a significant "chicken-and-egg" problem: infrastructure investment requires a critical mass of CVs, but the vehicles' optimal operation relies on non-existing infrastructure.

The National ITS Architecture aimed to address these challenges by offering a comprehensive, top-down framework for interconnected transport systems. However, it resulted in extensive documentation that was often ignored by those implementing advanced technologies. This approach contrasts sharply with the evolution of more successful systems, such as the internet, which grew organically through a collaborative "Request for Comments" process, and the US railroad system, which developed standards well into its decline in the 1920s.

This case study underscores the fact that for standards and technologies to gain adoption, they must deliver immediate, incremental benefits rather than relying solely on promises of future value. The failure of the National ITS Architecture highlights the importance of designing systems that provide tangible improvements at each stage of deployment to sustain investment and interest.

7.2. Successful Standards

This section highlights significant successes in standardization within the transit industry over the past decade, specifically examining transit data through General Transit Feed Specification (GTFS) (Section 7.2.1) and bikeshare data through General Bikeshare Feed Specification (GBFS) (Section 7.2.2).

7.2.1. Transit Data—GTFS (Experience)

The General Transit Feed Specification (GTFS) is a transformative standard that revolutionized how transit agencies communicate schedules to software applications, improving route planning for users worldwide. It originated in 2005 when Google Maps engineer Chris Harrelson and Portland's TriMet transit agency collaborated to format transit schedules in a way that could be seamlessly integrated into Google Maps. This partnership, initially called the Google Transit Feed Specification, set a precedent that was quickly adopted by other cities [46,47].

GTFS initially provided a static representation of transit systems based on fixed timetables, significantly enhancing the efficiency and user experience for transit passengers. It filled a critical gap in the absence of a national standard for representing transit schedules, facilitating the widespread analysis of transit accessibility in both the United States and globally [48].

Recognizing the limitations of static data in dynamic transit environments, GTFS-realtime (GTFS-RT) was developed alongside advances in automatic vehicle location (AVL) technology. GTFS-RT provides real-time updates on vehicle locations, projected arrival times, and stop schedules, significantly enhancing the accuracy and reliability of transit apps. More recently, GTFS-RT has included data on vehicle occupancy, an increasingly relevant feature for managing capacity during pandemics and other public health crises.

Today, GTFS standards are maintained and expanded by MobilityData, a nonprofit organization based in Montreal. MobilityData collaborates with key stakeholders, including state governments, leading tech companies, and transit agencies, to ensure the continued relevance and usability of the standards [49]. Data compliant with GTFS are often provided by local transit agencies and have even been retroactively applied to historical datasets for studying transit system evolution [50].

Despite its successes, GTFS faces challenges in regions reliant on informal transit services, such as dollar vans, jitneys, and other non-scheduled transport modes common in developing countries. These services often lack documentation or fixed schedules, complicating efforts at standardization [51,52]. However, organizations like WhereIsMyTransport are working to adapt GTFS for informal transit networks, thereby improving accessibility and operational analysis in emerging markets [53].

Proposals to further expand GTFS include GTFS-ride for standardizing ridership data and the General On-demand Feed Specification (GOFS) for on-demand transit services. Such expansions underscore GTFS's flexibility and its potential to adapt to new challenges within the transit sector.

In comparison, more complex standards like NeTEx in Europe and TransXChange in the UK have seen limited adoption, likely due to their greater complexity and regional specificity.

The success of GTFS not only enhanced transit accessibility and efficiency but also demonstrated the potential of well-designed standards to address evolving challenges in the transport system. Its adaptability and widespread adoption highlight its critical role in modernizing transit services globally.

7.2.2. Bikesharing—GBFS (Experience)

The digitally enabled New Mobility—including car-sharing, bikesharing, shared micromobility (electric bikes and scooters), ridehailing, and related services that expanded rapidly during the 2010s—has prompted new thinking about standards.

Some shared bike and scooter companies have made their data available to government agencies and researchers. Standardizing these data has significant value, as it reduces the number of tools needed for analysis, minimizes the time spent processing data, and decreases errors associated with inconsistent definitions.

The real-time General Bikeshare Feed Specification (GBFS), modeled on GTFS, exemplifies this shift toward standardization. First drafted in 2014 by Mitch Vars of Minnesota's NiceRide bikesharing system and adopted by the North American Bikeshare Association (NABSA) in 2015, GBFS was quickly embraced by vendors and is now used by more than 450 operators. It includes data on bike and station locations, bike and dock availability, station status, and business rules. The standard, maintained by MobilityData on behalf of NABSA, has been updated to accommodate stationless bikes. Its applications range from trip planning and mapping to geofencing solutions for ensuring bikes are stored in regulated areas. GBFS also supports integration with maps and may facilitate various Mobility-as-a-Service (MaaS) applications.

GBFS illustrates how standards like GTFS can inspire further innovation, enabling incremental advancements. Extensions to GBFS, such as support for virtual stations and other geofencing applications, demonstrate its flexibility in adapting to emerging needs and technologies. By fostering compatibility across platforms, GBFS plays a critical role in optimizing new mobility systems for users, operators, and policymakers alike.

7.3. Emerging Standards

Building on the model established by GTFS, new standards are emerging across various sectors of urban mobility. These standards aim to enhance efficiency, improve data interoperability, and address the unique challenges of modern transport modes. This section explores proposed standards for micromobility and ridehailing data (MDS) (Section 7.3.1), curbs (Section 7.3.2), parking (Section 7.3.3), and traffic signal status (Section 7.3.4).

7.3.1. Micromobility and Ridehailing—MDS

The City of Los Angeles pioneered the Mobility Data Specification (MDS) to manage the rapidly expanding field of micromobility, including shared bikes and scooters, and later extended it to encompass ridehailing vehicles. MDS aims to create a "digital twin" of urban mobility, accurately reflecting the real-time spatial and temporal distribution of vehicles and users [54,55].

Initially focused on micromobility, MDS was quickly adapted to address ridehailing vehicles, targeting challenges such as zero-occupancy vehicles roaming urban streets. Its development was driven by the need to regulate new mobility services effectively and prevent issues like improperly parked scooters and bikes, which have been observed to obstruct pathways, create clutter, and invite vandalism, as seen with shared bikes in Sydney [43]. Today, MDS is managed by the Open Mobility Foundation, with governance contributions from multiple cities [55].

Despite its potential benefits, MDS has raised significant privacy concerns. Tracking detailed user movements conflicts with privacy rights and freedom of movement, with critics warning that such surveillance could be misused for discriminatory practices or excessive government control. These concerns echo historical precedents where mobility data were exploited to oppress certain groups [56].

Webb [57] highlights the need for caution in implementing MDS, emphasizing a balance between regulatory convenience and individual privacy rights. In response, updates to MDS have incorporated enhanced privacy protections, though debates over their adequacy persist [58].

The conversation around MDS also involves significant opposition from stakeholders like Uber, which has contested broad data-sharing requirements through legal challenges and advocacy, citing rider privacy protection as a primary concern [59,60]. These ongoing disputes underscore the struggle between protecting individual rights and delivering societal benefits, reflecting the broader tension in modern urban mobility governance.

7.3.2. Curb Standards

The curb, often overlooked but a critical component of urban infrastructure, plays a pivotal role in managing public right-of-way interactions. It serves as the boundary between road surfaces and pedestrian spaces, and despite its understated presence, the management of curb space can spark intense local government debates. These discussions typically revolve around parking regulations and the allocation of curb real estate for various uses, such as bike lanes or bus lanes, underscoring its significance in urban planning.

Curb standards are essential for regulating curbside uses, including on-street parking, loading zones, and bus stops. While local municipalities have traditionally handled these regulations, there is growing interest in dynamic approaches to curb management. Dynamic loading and unloading permits, for instance, could allow cities to adapt to the growing demand for ridehailing services while potentially increasing municipal revenues.

The adoption of standardized curb management practices offers clear benefits, comparable to those observed with the *Manual on Uniform Traffic Control Devices* (MUTCD). Established in the 1920s, the MUTCD standardized traffic signs across the United States, ensuring drivers universally understood road signs and reducing confusion and accidents [61,62]. Similarly, standardizing curb data could streamline software development, enhance efficiency, and reduce the need for municipalities to develop bespoke solutions for curb management.

Historically, curb regulations have been somewhat ad hoc and disjointed. Parking regulations, such as "No Parking" signs, are often standardized in documents like the MUTCD, but their implementation can be complex and difficult to interpret, as illustrated in Figure 4. Moreover, these regulations frequently lack a strategic long-term vision or coherence, and comprehensive mapping that illustrates their collective impact across a city is often absent.

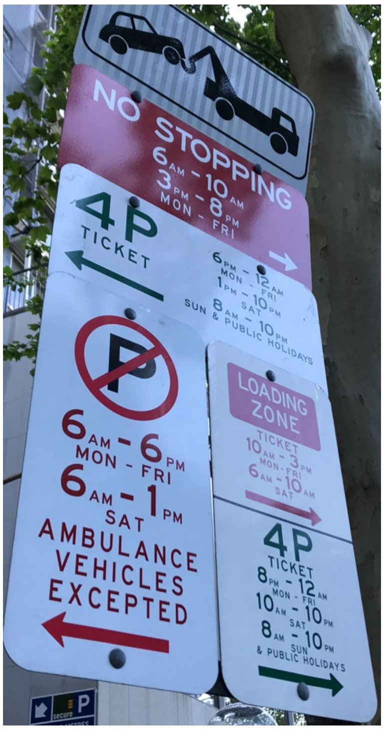

Figure 4. Example of a confusing parking sign, illustrating the complexity of curb regulations. Source: [63].

The Open Mobility Foundation's Curb Management Working Group seeks to address these issues by developing standards that could transform how municipalities manage and represent curb space data. This initiative aims to create a framework that not only maps physical signage but also digitizes regulations into a format that is universally understandable and applicable.

While the emerging standards for curb management promise to transform curb use and regulation, concerns remain about corporate influence in the standards-setting process. The risk of corporate capture, where private interests dominate public policy outcomes, poses a significant challenge. Additionally, competing standards could lead to a fragmented approach to curb management if not carefully coordinated.

In essence, the development of curb standards is not just a technical endeavor but a complex negotiation involving technical, political, and corporate interests, all of which will shape the future of urban mobility.

7.3.3. Parking

While on-street parking data are closely linked to curb data, a truly comprehensive parking data system must also encompass off-street parking to effectively serve both consumers and communities. Such a system should include information on parking price, availability, and utilization across various types of parking facilities.

Historically, some cities with municipal parking structures have successfully integrated these data. For instance, variable message signs in cities like St. Paul, Minnesota, have displayed parking availability in major ramps, informing commuters, shoppers, and event-goers of available spaces and reducing the time spent searching for parking.

Park-and-ride facilities, part of the urban landscape since the 1930s, allow travelers to park in designated lots and connect with bus or rail services. Initially informal, these facilities were formalized in cities like Detroit in the 1930s and expanded during events such as the 1939 World's Fair by the Long Island Railroad, demonstrating their long-standing role in supporting public transport [64,65].

Despite these advances, a standardized approach to representing parking data across multiple cities remains elusive. This challenge is particularly pronounced in environments where private entities control parking supplies, as occupancy data are often considered commercially sensitive. Platforms like SpotHero and Parkopedia provide visibility in prices, while apps such as Passport Labs and ParkMobile enable payment management. However, these systems lack standardization, resulting in a proliferation of proprietary solutions [66].

The Alliance for Parking Data Standards (APDS) is working to address these issues by promoting an open parking data standard similar to GTFS for transit. This initiative, supported by the UK Department for Transport and other stakeholders, seeks to integrate both on-street and off-street parking data. It also redefines curbs as a unique parking asset rather than merely another part of the roadway [67].

Specialized parking needs, such as overnight truck parking at rest areas, underscore the importance of comprehensive data coverage. Apps like Trucker Path source parking data from regional systems like Florida DOT's TPAS and MAASTO's TPIMS, but gaps in data coverage remain. Standardizing this information could improve safety by reducing the need for truckers to drive tired in search of parking, a critical issue given the limited availability of overnight spaces [64].

However, developing a standardized approach to parking data faces numerous challenges. These include the cost of data collection, competitive pressures between private operators, and privacy concerns. Additionally, states may hesitate to impose fees on rest areas, fearing they could discourage necessary rest breaks for drivers. Balancing data availability, privacy, affordability, and adoption remains a persistent hurdle in achieving comprehensive parking data standards. Even if standards are promulgated, their adoption is not guaranteed, underscoring the complexity of standardizing parking in a fragmented sector.

7.3.4. Traffic Signals

Urban pedestrians typically spend 20% to 30% of their walking time waiting at intersections, which not only reduces efficiency but also increases exposure to pollution.

Consider the potential of a wearable device application, named *Green Pace*, which uses haptic feedback to synchronize a pedestrian's walking speed with traffic signals. This device would adjust its feedback to encourage speeding up or slowing down based on real-time signal changes, aiming to ensure that the pedestrian reaches the Walk signal at each intersection. Such technology could significantly reduce waiting time, alleviate sidewalk crowding, and minimize exposure to pollutants at intersections. While watches with haptic feedback are already commercially available, the lack of real-time traffic signal data with accurate phase changes and schedules hinders the development of such applications. This issue is further complicated by the adaptive nature of many modern traffic signals.

Despite the relative simplicity of traffic signals, the integration of their operational data into user-friendly technologies like *Green Pace* remains a significant challenge. The traffic signal sector has struggled to standardize its data, limiting the development of applications that could enhance pedestrian mobility and efficiency.

In the late 1990s, US-based organizations including NEMA, ITE, and AASHTO, in collaboration with signal manufacturers, established the National Transport Communications for ITS Protocols (NTCIP). The goal was to create a standardized communication protocol ensuring interoperability between traffic control equipment from various manufacturers [68]. While this initiative aimed to prevent technological lock-in and promote equipment compatibility, rapid technological advances led to the development of manufacturer-specific management information bases (MIBs), which are not interoperable.

Efforts like the #FreeTheMIBS campaign have since emerged to address these issues, advocating for open and compatible standards [69]. However, challenges remain, including the need for widespread adoption and updating of traffic signal control units to reflect new standards.

The potential use of traffic signal data for applications like *Green Pace* could greatly enhance urban mobility by reducing the time vehicles and pedestrians spend idling at intersections, thereby decreasing fuel consumption and emissions. However, the large-scale deployment of such technologies remains limited. For example, the Audi Green Light Optimized Speed Advisory (GLOSA) system is operational at only a few thousand intersections [70,71].

Additionally, broader issues such as data privacy, equitable access to technology, and the potential monetization of traffic signal data pose further hurdles to the universal implementation of these innovations. As the sector evolves, the development of open standards that can adapt to technological advances while addressing these concerns will be crucial for the future of urban transport networks.

7.4. Missing Standards

This section discusses various domains within urban and transport planning that still lack comprehensive standards. These include street cross-sections (Section 7.4.1), traffic count and speed data (Section 7.4.2), and real-time toll and pricing data (Section 7.4.3).

7.4.1. Cross-Sections

Despite some municipalities providing open public data on street cross-sections, detailed descriptions of lane widths, markings, medians, footpaths, and verges are typically absent in resources like OpenStreetMap. A standardized representation of these elements would not only facilitate planning and engineering but could also regulate more precise vehicle movements, particularly in a future dominated by autonomous vehicles.

7.4.2. Traffic Count and Speed Data

Accurate and comprehensive traffic data, including vehicle counts, turning movements, speeds, and precise vehicle locations, are essential for effective traffic management, urban planning, and the integration of modern navigation systems. However, the collection and standardization of such data remain inconsistent across different regions and road types.

In California, the *Performance Measurement System* (PeMS) serves as a robust platform for collecting and analyzing traffic data. Developed by the California Department of Transportation (Caltrans), PeMS aggregates data from approximately 40,000 sensors installed across the state's freeway network. These sensors provide real-time and historical data on traffic flow, speed, and occupancy, enabling the detailed performance analysis of the freeway system. PeMS integrates various data sources, including traffic detectors, incidents, lane closures, toll tags, vehicle classifications, weight-in-motion measurements, and roadway inventory [72].

Similarly, Minnesota's Department of Transportation (MnDOT) uses the *Intelligent Roadway Information System* (IRIS) to monitor and manage traffic on the state's freeway system. IRIS is an open-source Advanced Traffic Management System (ATMS) that collects real-time data from detectors placed along highways to measure traffic volume and speed. These data are archived and made available to the public through tools like DataExtract and DataPlot, which allow users to extract and graph detector data for analysis [73].

Despite the effectiveness of systems like PeMS and IRIS, a standardized data format across different traffic organizations is lacking. This inconsistency complicates data integration and tool development, limiting the utility of traffic data for broader applications. Standardizing traffic data formats would facilitate more efficient data sharing and analysis, enhancing the effectiveness of traffic management strategies and the development of navigation systems that rely on such data.

While PeMS and IRIS provide valuable data for freeway systems, comprehensive coverage across all road segments, including arterial roads and local streets, is still lacking. Expanding data collection efforts to encompass these areas is crucial for a holistic understanding of traffic patterns and for implementing effective traffic management solutions across entire urban networks.

The development and implementation of standardized traffic data collection and reporting systems are essential for improving traffic management and urban planning. Leveraging existing systems like PeMS and IRIS as models, efforts should be made to establish comprehensive, standardized traffic data systems that cover all road types and regions, facilitating better integration with modern navigation technologies and enhancing overall transportation efficiency.

7.4.3. Real-Time Tolls and Road Prices

While systems like E-ZPass in the northeastern United States demonstrate some level of standardization in electronic toll collection, significant gaps remain in toll interoperability both nationally and internationally. For example, an E-ZPass tag is incompatible with California's FasTrak system, illustrating the lack of a unified standard across regions. This issue extends to fare collection in public transport, where separate fare media are often required for different systems. However, progress is being made toward compatibility with generic payment methods like credit and debit cards, which simplify fare transactions for users.

Discovering the actual toll costs for a specific route also remains a challenge. While mapping services may indicate the presence of tolls on a route, they do not systematically provide specific cost information. Each toll-operating entity typically maintains its pricing independently, without a standardized method for dissemination. This inconsistency complicates travel planning, as users must rely on fragmented sources for pricing information.

The absence of a unified data feed for toll pricing not only limits transparency but also represents a missed opportunity to enhance travel efficiency. A standardized toll data system would enable real-time access to pricing information, allowing travelers to make informed route decisions and transportation planners to optimize traffic flow. Addressing these gaps in toll interoperability and pricing data would mirror broader efforts in transport data standardization, with the potential to reduce real-world costs and improve system efficiency.

7.5. Is Standardization the Enemy of Innovation?

Standards have long been integral to transforming transport and expediting the delivery of new mobility services such as electrification and automation. They are foundational across various industries, not just transport, helping to lower deployment costs and streamline design processes. Standards enable mass production, reducing costs not only for the final product but throughout the engineering process. Imagine if every engineer had to rediscover the principles of physics and mathematics independently—progress thrives on building upon the foundations laid by predecessors, adapting their achievements rather than starting anew.

In transport engineering, numerous standardizing documents centralize decision-making beyond individual engineers, incorporating collective wisdom codified in handbooks and standards. Prominent standardizing organizations in the United States include

- TRB—Transportation Research Board
  - Highway Capacity Manual, updated across decades
- AASHTO—American Association of State Highway and Transportation Officials
  - Policies and standards for rural highways and urban streets
- ITE—Institute of Transportation Engineers

    - Manuals like Trip Generation and Parking Generation
- FHWA—Federal Highway Administration
    - Manual on Uniform Traffic Control Devices (MUTCD), published in multiple editions
- NACTO—National Association of City Transportation Officials
    - Guides for street, bikeway, and transit street design
- CoTAM—Committee of the Transport Access Manual
    - Transport Access Manual (2020)

These standards form the backbone of public policy and are widely respected in academia and practice. However, they are not without critique. For instance, the Trip Generation manual has faced significant scrutiny for its applicability, while the NACTO guides offer a critique of AASHTO's traditional approaches, advocating for more tailored solutions in urban contexts.

The emphasis on standardization has transformed many transport professionals into technicians who apply standard manuals rather than innovate from first principles. This necessary stage of mass production excludes the freedom for the levels of individual genius seen in the 19th century with figures like Isambard Kingdom Brunel. While Brunel's innovative but non-standard railway gauge was groundbreaking, its lack of compatibility with other systems had costly implications.

Standardization, while essential, can stifle creativity and innovation by removing degrees of freedom and solidifying rules that may become outdated. For example, road designs accommodating the variability of human drivers may be unnecessarily wide for autonomous vehicles, leading to inefficient space use and increased environmental impacts.

As transport technologies evolve, it is crucial to adapt and refine standards to keep pace with innovation. Governments play a pivotal role in this process by adopting and promoting open standards for information interchange, benefiting all stakeholders—users, providers, and regulators alike. Negotiating and updating these standards through consensus ensures that the balance between innovation and the established benefits of standardization is maintained.

8. Discussion and Conclusions

In today's global economy, the seamless and efficient flow of information—both inter-institutionally (I2I) and between institutions and people (I2P and P2I)—is crucial for achieving the four Es: efficiency, equity, reduced negative externalities, and enhanced user experience. Information must flow as freely and efficiently as the people and goods in transport systems, with each disruption or inefficiency requiring users to expend additional effort to navigate from point A to point B.

Modern society comprises various *institutions*, including governmental bodies, corporations, and standards organizations. These institutions often operate semi-independently, following distinct trajectories that occasionally intersect through shared goals or regulatory requirements. This decentralized structure fosters resilience, ensuring that a single point of failure does not cascade into widespread detrimental effects.

However, institutions are not isolated entities. They depend on each other for essential inputs, particularly information. Ideally, information transfer would be complete, accurate, real-time, and high-resolution. Yet, achieving this ideal is challenged by technological limitations, privacy concerns, and institutional inertia.

Lessons Learned: Our exploration of standards in transport—spanning successful, failed, and emerging standards—yields several key insights:

- Standards facilitate efficient information exchange between institutions, enabling the emergence of new entities within the information ecosystem.
- Standardized data allow the development of applications that leverage this information to provide enhanced services, reducing the need for repeated data processing adaptations.
- Openness must accompany standardization; data should be freely accessible to maximize societal benefit, characterized as both *gratis* (free of charge) and *libre* (free to use creatively).
- Standards require champions and are most effective when they evolve from industry-led, bottom-up initiatives.
- Standards are dynamic and require ongoing revision and adaptation to remain relevant and effective.
- Establishing and maintaining standards requires a long-term commitment, often beyond the typical scope of individual organizations.

Despite the evident benefits, implementing standards is not straightforward. The contrast between the bottom-up success of the General Transit Feed Specification (GTFS) and the top-down failure of the National ITS Architecture underscores the importance of how standards are developed. Additionally, the patchy standardization in areas like traffic data highlights persistent gaps in transport information systems.

We must consider which other domains could benefit from a "GTFS" approach. How do we foster such initiatives? What current efforts show promise, and why have standards not been established in other areas? Successful standards function as platforms, facilitating transactions in two-sided markets by offering clear advantages to both data users and providers.

While private companies often prioritize short-term financial returns, governments are ideally positioned to mediate the establishment of standards. However, public entities are also constrained by election cycles and may lack the long-term focus necessary for standard development.

Standards, particularly those facilitating information sharing like GTFS, not only improve current systems but also enable future innovations. For emerging economies, adopting existing standards offers the opportunity to leapfrog developmental stages, avoiding inefficiencies that more developed countries had to endure.

Ultimately, standards create a framework that supports continuous improvement and adaptation to new technologies and challenges. They are living entities within the technological ecosystem, requiring ongoing care, revision, and advocacy to remain relevant and beneficial.

Funding: This research was funded by the World Bank as part of the Transformative Technologies in Transportation (P174016).

Acknowledgments: The author would like to thank Wenxin Qiao, Cecilia Briceno-Garmendia, Fernanda Ruiz-Nunez, Jacob Baskin, Kevin Webb, Yadi Wang, and Blaine Leonard for their comments and feedback on sections of this report. The author remains solely responsible for the content. An earlier version of parts of this text appears in Chapter 5 of Qiao, Wenxin; Briceno-Garmendia, Cecilia. 2024. Global Report—"Transformative Technologies in Transportation". Washington, DC, USA: World Bank. http://documents.worldbank.org/curated/en/099062723131522743/P1740161f1ed340501a69916d7b0d2bff11 (accessed on 26 November 2024).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Sperling, D. *Three Revolutions: Steering Automated, Shared, and Electric Vehicles to a Better Future*; Island Press: Washington, DC, USA, 2018.
2. Levinson, D.M.; Krizek, K.J. *The End of Traffic and the Future of Access: A Roadmap to the New Transport Landscape*; Network Design Lab: Lexington, KY, USA, 2017.
3. Huntington, S.P. *Political Order in Changing Societies*; Yale University Press: New Haven, CT, USA, 2006.
4. Levinson, D.M.; Krizek, K.J. *Planning for Place and Plexus: Metropolitan Land Use and Transport*; Routledge: Boca Raton, FL, USA, 2007.
5. Committee of the Transport Access Manual. Transport Access Manual: A Guide for Measuring Connection Between People and Places; Technical Report; University of Sydney: Sydney, Australia, 2020.
6. Taylor, B.D. Unjust Equity: An Examination of California's Transportation Development Act. *Transp. Res. Rec.* **1991**, *1297*, 85–92.
7. Foth, N.; Manaugh, K.; El-Geneidy, A.M. Towards equitable transit: Examining transit accessibility and social need in Toronto, Canada, 1996–2006. *J. Transp. Geogr.* **2013**, *29*, 1–10. [CrossRef]
8. Cao, M.; Zhang, Y.; Zhang, Y.; Li, S.; Hickman, R. Using different approaches to evaluate individual social equity in transport. In *A Companion to Transport, Space and Equity*; Edward Elgar Publishing: Northampton, MA, USA, 2019.
9. Zhu, S.; Levinson, D. Do people use the shortest path? An empirical test of Wardrop's first principle. *PLoS ONE* **2015**, *10*, e0134322. [CrossRef]
10. Di, X.; Liu, H.X.; Zhu, S.; Levinson, D.M. Indifference bands for boundedly rational route switching. *Transportation* **2017**, *44*, 1169–1194. [CrossRef]
11. Carrion, C.; Levinson, D. Over-and under-estimation of travel time on commute trips: GPS vs. self-reporting. *Urban Sci.* **2019**, *3*, 70. [CrossRef]
12. Cui, M.; Levinson, D. Full cost accessibility. *J. Transp. Land Use* **2018**, *11*, 661–679. [CrossRef]
13. Yeganeh, A.J.; Hall, R.P.; Pearce, A.R.; Hankey, S. A social equity analysis of the US public transportation system based on job accessibility. *J. Transp. Land Use* **2018**, *11*, 1039–1056.
14. Palmateer, C.R. The Distribution of Access: Evaluating Justice in Transport. Ph.D. Thesis, University of Minnesota, Minneapolis, MN, USA, 2018.
15. Ben-Joseph, E.; Szold, T.S. *Regulating Place: Standards and the Shaping of Urban America*; Psychology Press: London, UK, 2005.
16. Ben-Joseph, E. Commentary: Designing codes: Trends in cities, planning and development. *Urban Stud.* **2009**, *46*, 2691–2702. [CrossRef]
17. Markoff, J. Google Cars Drive Themselves in Traffic. *New York Times*, 2010. Available online: https://www.nytimes.com/2010/10/10/science/10google.html (accessed on 26 November 2024).
18. Crespo, Y. Uber v. Regulation: 'Ride-Sharing' Creates a Legal Gray Area. *Univ. Miami Bus. Law Rev.* **2016**, *25*, 79.
19. Nelson, G. Tesla Beams Down 'Autopilot' Mode to Model S. *Autonews*, 2015. Available online: https://www.autonews.com/article/20151014/OEM06/151019938/tesla-beams-down-autopilot-mode-to-model-s (accessed on 26 November 2024).
20. Bowker, G.C.; Star, S.L. *Sorting Things Out: Classification and Its Consequences*; MIT Press: Cambridge, MA, USA, 2000.
21. Lampland, M.; Star, S.L. *Standards and Their Stories: How Quantifying, Classifying, and Formalizing Practices Shape Everyday Life*; Cornell University Press: Ithaca, NY, USA, 2009.
22. Alder, K. The measure of all things: The seven-year odyssey and hidden error that transformed the world. *Technol. Cult.* **2003**, *44*, 810–812. [CrossRef]
23. Blaise, C. *Time Lord: Sir Sandford Fleming and the Creation of Standard Time*; Vintage: New York, NY, USA, 2011.
24. Ben-Joseph, E. *The Code of the City: Standards and the Hidden Language of Place Making*; MIT Press: Cambridge, MA, USA, 2005.
25. Kwan, C.H. Foreign Exchange Policy Cannot Solve Structural Problems: A Policy-Mix Approach Is Needed. 2005. Available online: http://www.rieti.go.jp/en/china/05120702.html (accessed on 26 November 2024).
26. Malik, J.; Circella, G.; Alemi, F. Travel Behavior Impacts of Transportation Demand Management Policies: May is the Bike Month in Sacramento, California. In Proceedings of the 2019 hEART Conference, Budapest, Hungary, 4–6 September 2019.
27. Staunton, C.E.; Hubsmith, D.; Kallins, W. Promoting safe walking and biking to school: The Marin County success story. *Am. J. Public Health* **2003**, *93*, 1431–1434. [CrossRef] [PubMed]
28. Boarnet, M.G.; Anderson, C.L.; Day, K.; McMillan, T.; Alfonzo, M. Evaluation of the California Safe Routes to School legislation: urban form changes and children's active transportation to school. *Am. J. Prev. Med.* **2005**, *28*, 134–140. [CrossRef] [PubMed]
29. Teague, W.S.; Zick, C.D.; Smith, K.R. Soft Transport Policies and Ground-Level Ozone: An Evaluation of the "Clear the Air Challenge" in Salt Lake City. *Policy Stud. J.* **2015**, *43*, 399–415. [CrossRef]
30. Levinson, D.M.; Huo, H. Effectiveness of Variable Message Signs Using Empirical Loop Detector Data. 2003. Available online: https://hdl.handle.net/11299/179809 (accessed on 26 November 2024).
31. UNEP. *Used Vehicles and the Environment: A Global Overview of Used Light Duty Vehicles: Flow, Scale, and Regulation*; Technical Report; UNEP: Nairobi, Kenya, 2020.
32. HTEI. *Used Vehicles Exported to Africa: A Study on the Quality of Used Export Vehicles*; Technical Report; HTEI: Den Haag, The Netherlands, 2020. Available online: https://www.ilent.nl/binaries/ilt/documenten/leefomgeving-en-wonen/stoffen-en-producten/chemische-stoffen-en-mengsels/rapporten/used-vehicles-exported-to-africa/Used+vehicles+exported+to+Africa.pdf (accessed on 26 November 2024).

33. Van Wee, B.; De Jong, G.; Nijland, H. Accelerating car scrappage: A review of research into the environmental impacts. *Transp. Rev.* **2011**, *31*, 549–569. [CrossRef]
34. SSATP; PPIAFP. *Managing Motor Vehicle Stocks in Developing Countries and the Global Trade in 2nd-Hand Vehicles and Vehicle Parts that Supply Them*; Technical Report; The World Bank: Washington, DC, USA, 2021.
35. Arthur D Little. The Rapid Growth of Bike Sharing in China—Good News for City Mobility? Technical Report. 2017. Available online: https://www.adlittle.com/sites/default/files/viewpoints/adl_bike_sharing.pdf (accessed on 26 November 2024).
36. Fan, Y.; Zheng, S. Dockless bike sharing alleviates road congestion by complementing subway travel: Evidence from Beijing. *Cities* **2020**, *107*, 102895. [CrossRef]
37. Guo, Y.; Yang, L.; Lu, Y.; Zhao, R. Dockless bike-sharing as a feeder mode of metro commute? The role of the feeder-related built environment: Analytical framework and empirical evidence. *Sustain. Cities Soc.* **2021**, *65*, 102594. [CrossRef]
38. Tang, H.; Zhou, D. Understanding the Competition and Cooperation between Dockless Bike-Sharing and Metro Systems in View of Mobility. *Sustainability* **2024**, *16*, 5780. [CrossRef]
39. Zhu, L. Meituan Acquires Mobike for $2.7b. *China Daily*, 2018. Available online: http://www.chinadaily.com.cn/a/201804/04/WS5ac4686aa3105cdcf6516438.html (accessed on 26 November 2024)
40. Team, M. Hello S-1. *The Micromobility Newsletter*, 2021. Available online: https://micromobility.substack.com/p/-hello-s-1 (accessed on 26 November 2024)
41. Zhang, J. Shared Bikes in Beijing Subject to New Policies. *China Daily*, 2020. Available online: http://global.chinadaily.com.cn/a/202002/26/WS5e55e4bca31012821727a76c.html (accessed on 26 November 2024)
42. Qiu, M. How Shared Bikes Are Dispatched. *Southern Metropolis Daily*. Available online: https://www.sohu.com/a/200265528_161795 (accessed on 26 November 2024).
43. Heymes, C. Stationless in Sydney: The Rise and Decline of Bikesharing in Australia. *Findings*, 12 March 2019. [CrossRef]
44. Theseira, W. *Congestion Control in Singapore*; International Transport Forum: Paris, France, 2020. Available online: https://www.itf-oecd.org/congestion-control-singapore (accessed on 26 November 2024).
45. Terrill, M.; Emslie, O.; Fox, L. *Megabang for Megabucks: Driving a Harder Bargain on Megaprojects*; Technical Report; Grattan Institute: Carlton, Australia, 2021. Available online: https://grattan.edu.au/report/megabang-for-megabucks/ (accessed on 26 November 2024).
46. McHugh, B. Pioneering Open Data Standards: The GTFS Story. In *Beyond Transparency: Open Data and the Future of Civic Innovation*; Code for America Press: San Francisco, CA, USA, 2013; pp. 125–136. Available online: https://beyondtransparency.org/chapters/part-2/pioneering-open-data-standards-the-gtfs-story/ (accessed on 26 November 2024).
47. Baskin, J. Why There's No GTFS for Curbs (Yet). *Coord*, 2018. Available online: https://medium.com/coord/why-theres-no-gtfs-for-curbs-yet-fbb12d8e2209 (accessed on 26 November 2024).
48. Wu, H.; Avner, P.; Boisjoly, G.; Braga, C.K.V.; El-Geneidy, A.; Huang, J.; Kerzhner, T.; Murphy, B.; Niedzielski, M.A.; Pereira, R.H.M.; et al. Urban Access Across the Globe: An International Comparison of Different Transport Modes. *npj Urban Sustain.* **2021**, *1*, 16. [CrossRef]
49. MobilityData. Members | MobilityData. 2021. Available online: https://mobilitydata.org/members/ (accessed on 26 November 2024).
50. Rayaprolu, H. Sydney's transit access: 1925–2020. In Proceedings of the Transport Research Association of New South Wales (TRANSW) Conference, Virtual, 17–19 November 2020.
51. Goldwyn, E. Anatomy of a new dollar van route: Informal transport and planning in New York City. *J. Transp. Geogr.* **2018**, *88*, 102309. [CrossRef]
52. Palu, D.S. Introducing Bus Stop Policy in Samoa. Master's Thesis, University of Sydney, School of Civil Engineering, Darlington, Australia, 2019.
53. Peralta-Quiros, T.; Kerzhner, T.; Avner, P. *Exploring Accessibility to Employment Opportunities in African Cities: A First Benchmark*; The World Bank: Washington, DC, USA, 2019.
54. Carey, C. How Los Angeles Took Control of Its Mobility Data. *Cities Today*, 2020. Available online: https://cities-today.com/how-los-angeles-took-control-of-its-mobility-data/ (accessed on 26 November 2024).
55. Bliss, L. Why Real-Time Traffic Control Has Mobility Experts Spooked. *CityLab*, 2019. Available online: https://www.bloomberg.com/news/articles/2019-07-19/why-cities-want-digital-twins-to-manage-traffic (accessed on 26 November 2024).
56. United Nations. *Universal Declaration of Human Rights*; Technical Report; United Nations: New York, NY, USA, 1948. Available online: https://www.un.org/en/about-us/universal-declaration-of-human-rights (accessed on 26 November 2024).
57. Webb, K. Local Power in the Age of Digital Policing. *Triangulator*, 2020. Available online: https://triangulator.org/blog/local-power-digital-policing/ (accessed on 26 November 2024).
58. OMF Staff. *MDS Version Guidance*; Open Mobility Foundation: Burlington, MA, USA, 2023. Available online: https://www.openmobilityfoundation.org/about-mds/mds-version-guidance/ (accessed on 26 November 2024).
59. Plautz, J. Uber, Privacy Groups Form Coalition to Fight City Data Collection. *Smart Cities Dive*, 2020. Available online: https://www.smartcitiesdive.com/news/uber-privacy-groups-coalition-CARS-data-collection-MDS/573182/ (accessed on 26 November 2024).
60. Zefo, R. Standing Up for Rider Privacy in Los Angeles. *Medium*, 2020. Available online: https://medium.com/uber-security-privacy/ladot-mds-privacy-1eafbc412550 (accessed on 26 November 2024).

61. Hawkins, G. Evolution of the MUTCD: Early standards for traffic control devices. *ITE J.* **1992**, *7*, 23–26.
62. Hawkins, G. The MUTCD Turns 80: Time for a Makeover? *ITE J.* **2015**, *85*, 14.
63. Martino, M. Can You Decipher These Confusing Parking Signs? *ABC News*, 2019. Available online: https://www.abc.net.au/news/2019-03-21/quiz-sydney-confusing-parking-signs/10683014 (accessed on 26 November 2024).
64. Noel, E.C. Park-and-ride: Alive, well, and expanding in the United States. *J. Urban Plan. Dev.* **1988**, *114*, 2–13. [CrossRef]
65. Bullard, D.L.; Christiansen, D.L. *Guidelines for Planning, Designing and Operating Park-and-Ride Lots in Texas*; Technical Report; Texas Department of Transportation: Houston, TX, USA, 1983.
66. Hawkins, A.J. Google Maps Will Now Let You Pay for Public Transportation and Parking Through Its App. *The Verge*, 2021. Available online: https://www.theverge.com/2021/2/17/22287043/google-maps-pay-parking-public-transportation-cities (accessed on 26 November 2024).
67. APDS. ISO Formally Adopts Global Parking Data Specification Based on APDS Specifications. 2022. Available online: https://www.allianceforparkingdatastandards.org/iso-formal-adoption (accessed on 26 November 2024).
68. NTCIP Joint Committee. How to Get MIBs. Available online: https://www.ntcip.org/how-to-get-mibs/ (accessed on 26 November 2024).
69. #FREEtheMIBS. Technical Report. 2019. Available online: https://www.freethemibs.org (accessed on 26 November 2024).
70. Hawkins, A.J. Audi's Traffic Light Sensor Gives You the Power to Catch as Many Green Lights as Possible. *The Verge*, 2019. Available online: https://www.theverge.com/2019/2/19/18229947/audi-traffic-light-sensor-green-wave-v2i (accessed on 26 November 2024).
71. Autovision News. Audi Traffic Light Information: A Brief History and How It Works. *Autovision News*, 2020. Available online: https://www.autovision-news.com/safety/audi-traffic-light-information/ (accessed on 26 November 2024).
72. California Department of Transportation. PeMS Data Source. 2024. Available online: https://dot.ca.gov/programs/traffic-operations/mpr/pems-source (accessed on 26 November 2024).
73. Minnesota Department of Transportation. Mn/DOT Data Tools. 2024. Available online: http://data.dot.state.mn.us/datatools/ (accessed on 26 November 2024).